FACTORS CONTROLLING THE ABUNDANCE OF AQUATIC RESOURCES IN THE SAN FRANCISCO BAY/ SACRAMENTO-SAN JOAQUIN DELTA ESTUARY

FACTORS CONTROLLING THE ABUNDANCE OF AQUATIC RESOURCES IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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INTRODUCTION

The purpose of this paper is to summarize current understanding of the factors controlling the abundance of fishery resources and the food chain that supports them in the Sacramento-San Joaquin Estuary.

This is only one element in a series which needs to be considered by the Bay-Delta Oversight Council (BDOC) in formulating a plan which considers fishery resources adequately. To place it in perspective, a logical progression of planning elements is:

1. Define the status of aquatic resources--a report on this subject accompanies this report.

2. Establish objectives for resource management. An early responsibility of BDOC is to recommend such objectives.

3. Identify factors controlling resources. This is the purpose of this report.

4. Use the knowledge of controlling factors to select and evaluate alternatives to accomplish the objectives identified during Step 2. This and the next step will be a subsequent assignment of BDOC.

5. Select a set or sets of alternatives which will accomplish the selected management objectives.

In considering the factors controlling resource abundance, the factors could be categorized in either of two ways. One would be to examine each of the species for which substantial knowledge exists and describe the various factors controlling its abundance. The goal would be to provide a comprehensive understanding of causes for changes in the abundance of the species.

The second way would be to select the physical and biological factors thought to be important and describe how each factor affects various species. For example, one physical factor is the diversion of water from the Sacramento River into the central Delta through the Delta Cross Channel and Georgiana Slough. That diversion affects salmon, striped bass, Delta smelt, sturgeon, and shad.

The second approach was used in this paper because it is more consistent with the fourth planning step i.e., the alternatives selected during the fourth planning step described above will be combinations of measures designed to affect the various physical and biological factors in a desired way, e.g., limiting diversions of water through the Delta Cross Channel and Georgiana Slough.

These descriptions of consequences will provide a basis for judging generally how a set of measures will affect a given species, thus providing the initial basis for selecting sets of measures in Element 4. During that evaluation, the overall benefit of all measures included in the alternative would be estimated for each species and the measures would be modified as appropriate to attain objectives.

The comprehensive program initiated by the Governor focuses on water management actions necessary to satisfy various needs. Certain factors controlling fishery resources are related directly to those water management measures and are so identified in this paper. Some of these directly related factors suggest a need for water project operating criteria while others suggest a need for changes in the design of water delivery facilities.

BDOC also needs to consider other controlling factors in its planning process to identify measures desirable to complement water management measures and be confident that some non water management factors will not prevent realization of expected benefits from water management.

This paper makes a case for certain factors related to water projects being the principal factors currently controlling the abundance of specific fisheries. Certainly, those are not the only controlling factors, and the paper goes on to provide a perspective on the relative roles of various factors other than water project construction and operation.

As a final introductory point, we must accept the challenge of selecting management measures despite uncertainties as to their biological consequences. The estuary is simply too complicated and our understanding of it too limited to permit precise estimates of consequences. Furthermore, the estuary is constantly changing, so a relationship observed in the past may not be a good predictor of the future, and many management decisions pertain to conditions outside the limits of those observed. For example, we have never observed the consequences of diverting water from the estuary at the higher rates proposed for the future. Given those uncertainties, we need to use existing experience to select and implement measures appearing to have the highest probability of attaining objectives, evaluate the consequences and then adjust management actions as necessary to attain the objectives.

FACTORS RELATED TO CONSTRUCTION AND OPERATION OF WATER PROJECTS

Delta Inflow

The magnitude of flow coming down the rivers into the Estuary affects biological resources both in the rivers above the Estuary and in the Estuary. The principal identified effects within the Estuary are:

1. Striped bass eggs and larvae drifting down the Sacramento River are more likely to survive if flow rates sufficient to transport larvae to the Delta occur when the larvae are old enough to start eating. Limited evidence of poor survival of these early stages during low flows led the Department of Fish and Game (DFG) to propose a minimum flow of 13,000 cfs at Sacramento during the spring.

2. Various minimum flows for Chinook salmon in the Sacramento River system have been identified to protect salmon in the upstream spawning and rearing areas. While many biologists believe that flows in the Delta portion of the Sacramento River are also important to the survival of outmigrating salmon, a statistical model of salmon survival prepared by the U.S. Fish and Wildlife Service (USFWS) identified water temperature

and diversion rather than flow as the principal controlling factors in the Sacramento River.

In D-1485 the State Water Resources Control Board (SWRCB) included minimum flows at Rio Vista for the protection of salmon based on the intuitive judgment of DFG biologists. USFWS, DFG and the National Marine Fisheries Service (NMFS) supported a stronger version of those flows in the recent Bay-Delta hearings. (Most evidence on salmon needs in the Estuary is based on observations of the largest run ie. the fall run. Needs of other runs may differ, warranting caution in making management decision based on current understanding.)

3. Strong statistical relationships exist for the Tuolumne and Stanislaus rivers between flow in the spring and returning runs of adult salmon 2-1/2 years later. For the Tuolumne River, the relation dates back to estimates of spawning runs made in the late 1930s. While the general pattern of larger runs resulting from higher spring flows has held up to the present, it appears that the magnitude of the returning run for any given spring flow has diminished over the years. That indicates that habitat quality still improves with increasing river flow, but factors other than flow now

prevent runs from attaining historic levels. It seems likely that flow improves habitat quality both in and upstream from the Delta, but the relative importance of habitat quality in these two regions has not been quantified. USFWS, NMFS and DFG have advocated minimum flows in the San Joaquin River at Vernalis during the spring outmigration based on evidence that such flows would improve salmon survival in the Delta, but the benefit can not be quantified precisely.

4. The number of young American shad migrating seaward through the Estuary in the fall is strongly and positively related to the magnitude of flow in the previous spring. This likely indicates that increasing flow improves conditions in the rivers and upper Estuary for shad survival in the spring and summer.

5. The best year classes of white sturgeon tend to be produced in years when Sacramento River flows are high in the late winter and spring.

Diversions from the Sacramento River

Some of the water flowing down the Sacramento River is diverted by gravity into the lower San Joaquin River through three channels, Georgiana Slough, Three Mile Slough, and the Delta Cross Channel. Some fish follow the water both during their downstream and upstream migrations.

It is generally accepted that diversion of young fish from the Sacramento River decreases their survival, both by making them more vulnerable to direct and indirect effects of SWP\CVP diversions in the southern Delta and exposing them to other adverse conditions, such as elevated water temperatures, more predators and more agricultural diversions.

The principal quantitative evidence of such decreased survival is for salmon outmigrants. In April, May, and June, young hatchery reared salmon migrating downstream in the Sacramento River below Walnut Grove survive at about twice the rate of those diverted through the Cross Channel or Georgiana Slough. Since 2 percent or fewer of the salmon in the Sacramento River show up at the SWP/CVP fish screens in the south Delta most of this increased mortality must occur in the Delta channels. Thus for salmon migration during the spring, direct loss at the SWP/CVP intakes is less than the indirect mortality resulting from diversion out of the Sacramento River. Survival of salmon migrating earlier has not been evaluated.

Some upstream salmon migrants have always used the lower San Joaquin River-Mokelumne River-Georgiana Slough route on their way to the Sacramento system spawning grounds, and there is some indication that the proportion doing so increases in proportion to the amount of Sacramento River water following that route. This is believed to cause no harm so long as the channels are not blocked, including the present normal operating mode for closing the Delta Cross Channel.

Young of several other species, including striped bass, American shad, and Delta smelt, are also diverted from the Sacramento River during their downstream migration and are likely adversely affected. However, effects on their survival have never been measured as they have for salmon. One indication of such effects is the annual occurrence of hundreds of thousands to several million American shad, most of which come from the Sacramento system, in SWP/CVP salvage operations at fish screens in the South Delta.

The effect of diversion through Three Mile Slough has not been directly evaluated for fish; however, studies by the Contra Costa Water District suggest Three Mile Slough is a major transport route to the interior delta for ocean salts that enter the lower end of the Sacramento River during low flow periods. If that is true, Three Mile Slough would also serve as a major conduit for fish, particularly eggs and larvae transported by currents, to move from the Sacramento River to the interior Delta. Also, studies indicate young salmon may be diverted through Three Mile Slough (See discussion on next section).

Reverse Flows

The natural flow pattern in the Estuary is for freshwater flowing to the ocean to cause the average total flow during ebb (outgoing) tides to exceed the total flow during flood (incoming) tides. The SWP\CVP pumps in the southwestern Delta draw water towards the pumps. At certain times and locations their draw causes the total upstream flow during flood tide to exceed the total downstream flow during ebb tide. That is called reverse flow. Note that it is actually a tidally averaged net reverse flow. i.e. The tide still causes the flow to go back and forth but the net direction of movement is changed from downstream to upstream. Near the upstream limits of tidal action, freshwater flow is large in relation to tidal flow, so the difference between ebb and flood tide flows is easily measurable. As one moves downstream tidal flow becomes several orders of magnitude greater than net flow. For example at Chipps Island net flow is on the order of only 2% of tidal flow at typical summer minimums, and it has never been possible to measure flow precisely enough to ascertain net flows. In such cases estimates of net flow are derived from mathematical models.

The potential significance of reverse flow is that it tends to move fish and their food supply towards the export pumps rather than towards the ocean. One would expect this effect to be most significant where net flows are relatively large in relation to tidal flow, such as in Old and Middle rivers near the pumps. In fact it is questionable whether effects of modest reverse flows are significantly more detrimental than small positive flows to fish in areas such as the lower San Joaquin River, where net flows are so small in relation to tidal flow that net flows can't be measured by the best scientific instruments. While that is a legitimate question, some animals have characteristics which may override such logic. For example, opossum shrimp, a major animal in the food chain, move farther off the bottom during flood tides than during ebb tides. Since velocities near the bottom are less than those at mid-depth, the shrimp's migration pattern subjects them to being transported by flow more on flood tide than ebb tide. The sensory mechanism they use to do this is unknown, but it seems to be an obvious adaptive strategy to maintain their location in an estuary with a predominance of downstream flow. It would make them more vulnerable to upstream transport than suggested by the relative magnitude of net flows and tidal flows. We do not know whether any other species, including fish, behave similarly.

Net flow reversals occur essentially all the time now in Old and Middle rivers, about one half to three-fourths of the time in the lower San Joaquin River in many years, and frequently in the San Joaquin River from Middle River to the head of Old River below Mossdale.

The specific effects of reverse flow are confounded with other factors, particularly the magnitude of exports. It has not been possible to distinguish relative increases in mortality caused by reverse flows transporting fish to less favorable habitats from increases caused by losses in the SWP/CVP water diversions, which are discussed in the next section. An example of the combined effect is that the proportion of young striped bass occurring in the Delta has been about 20 percent less for any given amount of Delta outflow since 1970 than it was prior to 1970.

Both the mortality attributed to the ecological consequences of reverse flow and losses in the water diversions are caused by the magnitude of water diversions. Judgements as to the relative significance of the two sources of mortality are important because water project alternatives studied in the past have intrinsically different effects on the two sources. For example, the various through Delta alternatives and a Peripheral Canal might cause similar changes in reverse flow but have very different effects on the vulnerability of fish to the diversions.

Salmon smolts must use factors other than net velocity to help guide them through the Estuary, as their migration rate is considerably faster than the net velocity. Nevertheless, reverse flows may impede migration and have been investigated as a cause of mortality. Some quantitative support for adverse effects is provided from outmigrant studies in the San Joaquin River. In two experiments in 1989 and 1990 survival of salmon was 9 and 75 percent greater when flows were positive than when negative. Those results, in combination with releases made in 1991, produced a positive relationship between net flow and survival. There is also a positive correlation between survival of salmon released at Ryde on the Sacramento River and reverse flow on the lower San Joaquin River. That correlation suggests that reverse flow adversely affects salmon migrations through Three Mile Slough. Neither study is definitive due to variability in results and the small number of observations.

Losses in Water Project Diversions

Most evaluations of the factors affecting salmon survival in the Delta pertain to smolts migrating in the spring. Particularly in wet years a portion of both the fall- and winter-run enters the Delta as fry and rear there until they smolt and migrate to the ocean. Marked hatchery reared fry released in the Delta generally survive better than those released in the Sacramento River upstream from the Delta. That is the reverse of experiences with smolts. We do not know what role reverse flows or other factors play in determining the survival rate of fry rearing in the Delta.

The CVP exports water at rates up to about 4,600 cfs through their Tracy Pumping Plant and 250 cfs into Contra Costa Canal. The SWP exports water at rates up to about 6,400 cfs through their Banks Pumping Plant and 150 cfs into North Bay Aqueduct. The capacity of the Banks Pumping Plant has recently been increased to 10,300 cfs, but the Corps Public Notice limits average daily exports to the original capacity, except for some increase when San Joaquin River flows are high during the winter. Instantaneous export rates, however, can be as large as 10,300 cfs. DWR is preparing an EIR\EIS for the Interim South Delta Program seeking authority to increase average exports, and negotiations on mitigation measures are ongoing. In general, the CVP diversions are operated much nearer to capacity than SWP diversions.

Intakes to the Banks and Tracy pumping plants have louver fish screens of somewhat different design. The screens are ineffective for larval fish, which has important adverse effects on some species, but are on the order of 90% effective for fish several inches long. In addition to fish lost through the screens, fish die in the diversion system due to predation and stresses associated with the handling and trucking required to release them into the western Delta. Losses vary markedly for different species and sizes of fish, operating conditions and water temperatures.

A particularly significant issue concerns mortality in Clifton Court Forebay at the intake to Banks Pumping Plant. For example, approximately half to 95% of young hatchery-reared salmon released at the intake to the Forebay disappear before reaching the fish screens. The principal cause of this disappearance is probably predation by striped bass that has been enhanced by the Forebay design and operation. Studies are underway to define the problem better and to reduce losses. A major program is being planned for 1994 to remove striped bass from the Forebay and return them to the Estuary.

While certain improvements in the present screening system can and are being made, diversions from the south Delta present two inevitable problems. First, no flow can bypass the intake. Thus all fish must be captured and transported to another location for release. Substantial losses are inevitable in the process, especially for species or life stages which are easily stressed.

The more fundamental problem is that water is being withdrawn from a large "pool", albeit one which is sloshing back and forth with the tide, which is a major nursery for some fish and a permanent residence for others. The draw of water to the pumps diminishes the capacity of the "pool" to support fish populations by diverting both fish and their food supply from the "pool".

All fish species in the pool are not equally vulnerable to being drawn to the diversion. Seaward migrants, such as salmon and American shad, which follow the downstream flow of water and open water species, such as striped bass, delta smelt, longfin smelt, and splittail are particularly vulnerable. Species such as largemouth bass and tule perch, which reside near the shore where velocities are lower, are much less vulnerable.

As a final general point, before turning to the evidence of impact on individual species, the vulnerability of certain species varies with the magnitude of freshwater flow through the estuary. For example, when flows are high young striped bass are carried quickly into Suisun Bay, so the population of bass is much less vulnerable than when flows are low.

This interaction between flow and diversion effects makes it difficult to determine the actual controlling mechanisms. Most biologists agree that increasing flow both improves habitat quality for striped bass in the Suisun Bay nursery area and diminishes vulnerability of bass to diversions, but the relative importance of the two cannot be distinguished precisely. Thus

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considerable uncertainty exists as to minimum outflow needs even in the absence of diversions from the present location.

The remainder of this section will describe effects of losses in the SWP\CVP diversions for a few species.

Striped bass from egg stage through the first year of life and beyond are lost in diversions. Historical annual loss estimates of bass longer than 20 mm for the combined SWP\CVP diversions range from less than 1 million in two very wet years when exports were low and most bass were farther downstream to more than 113 million in 1974 when striped bass were more abundant than now and average combined SWP\CVP diversions exceeded 9,800 cfs for June through August. Estimated annual losses of smaller bass and eggs have ranged up to about 793 million since they were first measured in 1985. To provide some perspective on potential impacts on the bass population, DFG biologists estimated that losses of bass entrained by the SWP\CVP reduced the population before the 20 mm stage by more than 70% in three dry years and 32 percent in a wet year. DFG analyses also indicate that losses in SWP\CVP diversions throughout the first year of life are largely responsible for the adult population declining from about 1.7 million fish in 1970 to only about 700,000 fish in 1991. While there is not a consensus on the specifics of the DFG analyses among biologists, no biologist testifying during the recent Bay-Delta hearings before the State

Water Resources Control Board challenged a conclusion that SWP/CVP diversions have harmed bass significantly.

Losses of chinook salmon at SWP\CVP diversions in the south Delta have usually been between 400,000 and 800,000 in recent years, assuming an estimated mortality of 75% in Clifton Court Forebay. Estimates of the number of salmon migrating through the Delta are approximately 20 to 50 million. These losses are equivalent to a loss of 6,000 to 12,000 salmon in the fishery. Which is a small fraction of the total catch. The proportion of salmon from the San Joaquin system lost at SWP/CVP intakes is greater than the proportion of salmon lost from the Sacramento system but the proportion has not been quantified well. About 2 percent of the spring outmigrants from the Sacramento River show up at the intakes, while on occasions 20 to 70 percent of the San Joaquin outmigrants show up at the intakes.

Losses at the SWP/CVP diversions have been estimated only for striped bass and salmon, but the total number of fish captured at the screens is estimated for all species. The capture estimates for two other species are worth mentioning here to illustrate differences in the character of effects.

First, from 1968 through 1985, the number of American shad captured annually at the two facilities ranged from about 430,000 to 4.5 million. As contrasted to salmon, most shad must come from the Sacramento system as few shad spawn in the San Joaquin. Also, the percentage lost at the screens is greater, because shad are difficult to handle. Observations indicate that about 70 percent of the shad die in the handling process subsequent to their being "saved" by the screens while comparable losses of salmon are on the order of 5 percent.

Secondly, Delta smelt is another species which is vulnerable to being drawn to the export pumps. Typically, the largest numbers are captured in May, June, and July during and shortly after spawning. In some years, the pattern of Delta smelt occurrence deviates from this "norm". For example, during 1977 virtually no pumping occurred from May through November due to a drought. Pumping commenced in December when large storms broke the drought and the numbers of smelt captured increased rapidly. In fact, in January 1978, 134,000 Delta smelt were captured at the SWP screens. That almost equaled the number captured in all of 1977 and exceeds the annual total for all subsequent years. In effect 1977 was an unintended experiment in curtailing diversions much more than has ever been considered practical from a regulatory standpoint. It appeared to increase survival of smelt and several other fishes in the Delta temporarily, only to destroy the fish when pumping resumed. It provides dramatic evidence of the virtual impossibility of protecting those resident fish species which are easily transported by flow by seasonally curtailing diversions with the present physical configuration of the water delivery system.

Another consideration concerning delta smelt is very few survive capture and transport even under the best of conditions. Hence their survival during normal screening operations is likely even less than that observed for shad.

Temperature

Water temperature has a strong influence on the lives of all fish and their food supply. The normal seasonal cycle has important influences on life processes such as growth and the timing of spawning.

The principal identified temperature requirement in the Estuary is for cool temperatures to maintain salmon survival in the spring. Correlation analyses provide evidence that survival of young salmon decreases proportionately as temperature increases above 60° F. Since laboratory experiments indicate temperature is not lethal to salmon until temperatures reach 72° or 73° F, the observed relationship is probably due to some indirect effect. Increased activity by predators as temperature increases is one such possibility.

While this temperature need is included in this section describing factors of direct concern to BDOC, it might be more appropriate to include it in the next section on indirect concerns. Water operations definitely exert a major control over water temperature in upstream areas, but the Delta is so far from reservoirs that water temperature has largely come into equilibrium with air temperature. Analyses indicate that it is not feasible to influence water temperature in the Delta by manipulating reservoir releases in most, if not all, cases.

Delta Outflow

Outflow vs. Salinity Controversy

Delta outflow is the amount of water flowing past Chipps Island, at the western edge of the Delta, into San Francisco Bay. The magnitude of Delta outflow largely controls the intrusion of salt water from the ocean into the Estuary. Hence, Delta outflow and salinity intrusion are highly correlated.

Historically, the Department of Fish and Game and the U.S. Fish and Wildlife Service have described fishery protection measures for the western Estuary in terms of Delta outflow. Recently, a group of scientists convened by the Environmental Protection Agency proposed salinity standards be used in conjunction with and in preference to flow standards. Arguments for salinity center around its ecological importance and the fact that it can be measured accurately. While outflow is also of direct ecological significance, it can only be estimated. The estimates are subject to significant short-term errors associated with factors such as barometric pressure and wind, which either retard or accelerate the flow of water out of the Delta. Such errors, however, have little management significance, because management objectives are based on averages over 2 or more weeks, and the factors causing short-term errors in outflow estimates average out over several weeks.

For practical purposes, the analysis of needs and statement of management objectives will reach the same conclusion whether based on outflow or salinity. I believe the evidence indicates that the biological phenomena of primary interest are driven by flow rather than salinity. Hence this paper describes needs in terms of flow, except for a striped bass spawning need which is clearly driven by salinity.

A consideration of regulatory interest is that salinity standards may be more enforceable by the Environmental Protection Agency under the Federal Clean Water Act than flow standards. That controversy, however, is beyond the scope of this paper.

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Physics of Outflow

Freshwater flowing out of the Estuary tends to override salt water transported into the Estuary from the ocean by tidal action. This phenomenon results in a surface current of fresh water flowing towards the ocean, and a bottom salty current flowing inland on a tidally averaged basis. In many estuaries this results in a sharp vertical gradient between fresh and salt water. In the Sacramento-San Joaquin Estuary, however, tidal mixing forces are relatively large so the vertical gradient is relatively small except during very high outflows. In fact, the gradient almost disappears at low flow. It is still great enough, however, to have considerable ecological significance.

One consequence is that near the upper end of the salinity gradient suspended particles carried downstream by freshwater settle towards the bottom and get transported upstream by the flow along the bottom. This phenomenon affects both nonliving particles and small living organisms, such as phytoplankton, zooplankton and fish larvae. The net effect is an accumulation of suspended particles near the upper end of the salinity gradient, and hence the name entrapment zone for that segment of estuaries.

The entrapment zone tends to be an important fish nursery area in all estuaries due to the accumulation of biological material produced upstream. In addition in our Estuary, production in the entrapment zone tends to increase at moderate outflows. Increased production probably occurs because increased flows both strengthen the entrapment process and cause the zone to be located adjacent to shallow embayments in Suisun Bay. Better access to light causes phytoplankton production in the shallow embayments to be greater than in the deeper channels.

Bay Fishes and Invertebrates

The magnitude of Delta outflow strongly influences the distribution of almost all estuarine fishes and invertebrates. Generally, the greater the outflow the farther downstream fish and invertebrates occur.

Relationships between the magnitude of outflow and the overall abundance of fish and invertebrates are not nearly as general. In fact there is no obvious relationship between outflow and overall abundance for most fish and invertebrates. For several important species, however, strong positive relationships exist.

These relationships probably reflect one of two hydrodynamic processes. One process is the upstream transport, by bottom current, of young fish and invertebrates from spawning grounds in the Pacific Ocean or San Francisco Bay to nursery areas farther

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upstream. The strengthening of the bottom current by increasing outflow is probably responsible for starry flounder and a species of bay shrimp (Crangon franciscorum) being much more abundant when flows are high than when they are low.

The second process is the downstream transport of young by freshwater flow. The prime example is longfin smelt. They spawn in the Delta and their young are transported downstream to nursery areas mostly in Suisun and San Pablo bays. High flows increase their survival probably by a combination of spreading them over a larger area of the estuary and increasing their food supply as discussed in the previous section. No similar relationship has been identified for Delta smelt.

Longfin smelt, bay shrimp and starry flounder spawn in the winter and early spring and their abundance is positively related to outflow during the same period. In each case, the relationship exhibits substantial variability so benefits would be obvious only for fairly large incremental differences in outflow.

Commercial and angler records, however, indicate long-term declines in shrimp and starry flounder abundance. Also, during the recent drought longfin smelt have become so scarce that they have been proposed for listing as an endangered species and no young flounder were captured during DFG's 1992 survey. Thus it is probable that, due to reduced outflow during the winter and spring, the storage and diversion of water is the principal cause of long-term declines in these three species.

Striped bass -

Measurements dating back to 1959 indicate that young striped bass survival increases in proportion to Delta outflow during April through July. There is also evidence that Delta outflow continues to influence bass survival through December.

The DFG has prepared a statistical model which indicates that the survival of striped bass during their first year depends on the magnitudes of Delta outflow and state and federal exports, and that these first year conditions determine subsequent abundance of adults. While no consensus exists as to the model's validity, no biologists testifying in the recent Bay-Delta hearings challenged the contention that the combined effects of Delta outflow and exports are major factors controlling bass abundance.

It is likely that increasing Delta outflows improve young bass survival by spreading them over a larger nursery area and improving their food supply, as well as by reducing their exposure to CVP\SWP export pumps.

Chinook salmon -

Three years of sampling for salmon at the Golden Gate, indicates salmon smolts migrate through the lower estuary faster than net flow would transport them. In those three years, their survival rate in that reach was not related to the magnitude of Delta outflow.

SALINITY

The only fishery regulatory standard now in place which reflects a need clearly dependent on salinity is striped bass spawning objective in the San Joaquin River. Bass spawn in the freshest reach of the river. Typically, that reach is between the upper limit of ocean derived salinity near Antioch and increase salinities near Stockton resulting from land derived salts entering the Delta from the San Joaquin River. This reach of very freshwater is created by Sacramento River water flowing into the central Delta through the connecting channels as described earlier.

Bass generally spawn where salinity, expressed as electrical conductivity (EC), is less than 300 microsiemens and do not continue mitigating up the San Joaquin River past ECs greater than 550.

There is an ongoing debate about this salinity need from two perspectives. First, the DFG has sought to maintain appropriate salinities only from Antioch to a few miles below Stockton. The U.S. Environmental Protection Agency (EPA) and the USFWS have recently advocated extending the protection to Vernalis on the San Joaquin River which would require additional releases of water. It is uncertain whether the larger spawning area would increase production sufficiently to offset probable increased losses in CVP/SWP export pumps resulting from bass eggs spawned in the San Joaquin River above the Delta being more vulnerable to diversion through upper Old River.

Secondly, in some very dry years, many bass have spawned at higher salinities, but it isn't known whether they would abandon the spawning reach if salinities were consistently higher than the present standards.

A general expectation was that more saline conditions in San Francisco Bay would result in substantial increases in marine fishes and invertebrates in the Bay. That, however, generally has not been the case. Overall, during the drought, the abundance of fish decreased in all embayments except in South Bay and abundance decreased for more fish species than it increased. Of all embayments, San Pablo and Suisun bays were the most heavily impacted by the drought in terms of increases in salinity

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and decreases in the number of species of fish and fish abundance.

An exception was the gradual increase in the abundance of a more salt tolerant shrimp, Crangon nigricauda, in San Francisco Bay during the drought. While it became more abundant than the normally dominant bay shrimp, the total biomass of shrimp declined because C. nigricauda is smaller than bay shrimp.

Another interesting aspect of the change is C. nigricauda doesn't invade the Bay in large numbers in single drought years. Rather it seems to respond over several years to stable saline conditions. Thus, this species apparently is not well adapted to the dramatic salinity fluctuations which are typical of estuaries.

FACTORS UNRELATED TO WATER PROJECTS

Introduced Species

Introductions Prior to 1950

In the century between 1850 and 1950 humans introduced many fish and invertebrate species into the Estuary. Some introductions were a deliberate attempt to diversify the fish fauna. The native freshwater fish fauna was much less diverse in

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California than in the eastern United States. Hence a concerted effort was made to transfer freshwater and anadromous game fish from the East to California in the last half of the 19th century. Many invertebrates were also introduced, largely incidental to various commercial activities such as culturing oysters.

By 1950, the aquatic resources had changed dramatically. For fish the change was most dramatic in freshwater. For example, 17 of the 30 species salvaged at the SWP fish screens in 1980 were introduced species, with 13 having been introduced prior to 1950. In 1991, 7 of the 10 most abundant fish salvaged at the SWP screens were introduced. In contrast, only 5 of the 64 most common species collected from San Francisco Bay upstream through Suisun Bay during the 1980s were introduced prior to 1950. Thus the shift from native to introduced fish is much greater in the freshwater portion of the Estuary than in the salt and brackish water portion.

The sport catch of introduced species--striped bass, white catfish, largemouth bass, etc,--in the Estuary far exceeds the catch of native species.

These introductions must have affected the abundance of native fishes but little historical information exists on the abundance of native fishes. The most certain consequence probably was the elimination of Sacramento perch from the

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Estuary. The perch is a "primitive" member of the bass family and probably could not compete with the several members of the family introduced from the East.

Introductions Since 1950

The frequency of deliberate introductions has slowed since 1950, but accidental introductions probably have not decreased. The major source of accidental introductions has apparently been the exchange of ballast water by ships.

Among fishes, threadfin shad, introduced deliberately as a forage fish in the early 1960s; inland silversides, introduced illegally apparently in an attempt to control gnats in Clear Lake; yellowfin goby and chameleon goby have been the principal new species. The gobies apparently came from the Orient in ship ballast water.

The changes in invertebrate populations have been more dramatic than those for fish since 1950. Several new species of zooplankton have dramatically changed species composition in the brackish and freshwater portions of the Estuary. A clam, *Potamocorbula amurensis*, introduced in 1986 has dominated benthic populations, particularly in Suisun Bay and a newly introduced amphipod, *Gammarus daiberi*, has become a major food of young striped bass.

The ecological significance of these changes is uncertain. The most widely accepted evidence of a major consequence is the virtual disappearance during the summer and fall of the dominant native copepod, Eurytemora affinis, near the upper end of the salinity gradient. An oriental copepod, Pseudodiaptomus forbesi, largely replaced Eurytemora in the late 1980s. Eurytemora populations declined sharply during 1988 apparently in response to predation by the more recently introduced Potamocorbula.

The observations related to Eurytemora illustrate both the approach biologists use in making judgements about the consequences of species introductions and the uncertainties about the ultimate ecological effects. Eurytemora populations fell after Potamocorbula became abundant in Suisun Bay. Laboratory evidence indicates Potamocorbula can eat Eurytemora. Those observations support the hypothesis for the causes in Eurytemora's decline, but the consequences for fish are uncertain.

Eurytemora had been the principal initial food for striped bass larvae near the upper end of the salinity gradient. Much work has been done to try to determine whether food supply limits striped bass production. Most biologists interpret degree of food limitation exists, probably through slowing growth, thus increasing mortality rates. Yet no direct evidence of starvation of bass has been found. Bass have changed their diet as the composition of the available food supply has changed, and no general relationships have been found between food supply and bass mortality. Thus the changes in food supply caused by recent introductions are apparently not a major factor contributing to the decline of striped bass. Even if that is so, the changes in food supply might inhibit the recovery of some fish species.

The trends in the abundance of various fish species have also been examined to try to identify coincidences between trends which might indicate one species causing another to decline. No declines in abundance have coincided with increases in introduced species sufficiently for the introduced species to be the likely cause of observed declines.

A recent question has been raised about that conclusion in regard to Delta smelt and inland silversides. It has recently been hypothesized that the measures of silversides abundance are poor, because little sampling is done along the shoreline where most occur. Hence predation and competition with silversides may have been more significant for Delta smelt than previously recognized.

The best summary of the effects of introduced species is that introductions have caused major changes in fish fauna in the estuary, particularly in fresh waters. The most obvious effects on fish populations occurred due to introductions in the 19th century.

Introductions since 1950 have caused substantial changes in aquatic invertebrates and established large populations of several species of smaller fish, but they have not coincided with the principal declines in other fish populations. Hence there is not an strong empirical case for recent introductions being a principal cause of the decline in species such as striped bass and Delta smelt. Conversely, uncertainty exists both as to effects introductions may have had on some species and as to whether the introductions may make the recovery of previously abundant species more difficult.

Food Limitations

Many biologists suspect that food limitations may have played some role in the decline of fish populations, with most of the evaluation effort having been directed towards striped bass. Among the reasons for this suspicion are the fact that zooplankton are less abundant in this Estuary than in Atlantic Coast estuaries where large populations of bass occur. Also, the abundance of a number of components in the food chain has decreased since 1970. Even though total zooplankton abundance is about the same as it was 20 years ago.

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As discussed in the previous section on introductions, food supply probably does influence the survival of bass, but the available evidence does not provide any clear evidence that food limitations have contributed significantly to the decline in bass abundance.

TOXICITY

Forty years ago, a number of adverse effects of pollutants were obvious in the Estuary. These included low dissolved oxygen at several locations, fairly common kills of fish and obvious visual or olfactory changes associated with discharges. Today, after hundreds of millions of dollars spent to upgrade waste treatment, many fewer obvious signs of pollution exist.

The major question involving toxics is whether toxic deposits or continuing discharges, including those from nonpoint sources, cause toxic effects sufficient to affect the abundance of species significantly. Various sublethal effects have been documented well, but pollutant-effects experts are uncertain of the consequences of such effects, particularly as they relate to whole populations of fish.

One aspect of toxicant effects is that they are potentially confounded with flow effects. The magnitude of flow certainly dilutes concentrations of toxicants, particularly in the upper

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portion of the Estuary. As one moves downstream, tidal action becomes of increasing importance in determining rates of dilution. Within San Francisco Bay, tides are the dominant force determining dilution, except when relatively high flows ($\simeq$40,000 cfs) induce two-layer circulation.

While pollutant effects have been identified for a number of species, potential effects have been examined more thoroughly for striped bass than for other species. Hence the following discussion will focus on striped bass.

One source of information concerns periodic pesticide occurrence in runoff from the Sacramento and San Joaquin rivers. Biologically significant concentrations occur periodically even during pulse flows resulting from storms. Bioassays have demonstrated lethal effects for several invertebrates and larval striped bass both in the Sacramento and San Joaquin rivers. Also liver necrosis typical of exposure to toxic chemicals has been found in young bass in the wild. Yet no corresponding increase in mortality rates for young bass has been measured, and stringent controls, which clearly decreased pesticide loading in 1991 and 1992, produced no corresponding increase in young bass abundance. The decline in the abundance of young striped bass since the early 1970s is closely correlated with the amount of rice pesticides used along the Sacramento River. The failure of the abundance of young bass to increase in response to improved regulation of pesticides in 1991 and 1992 indicates that the correlation probably does not reflect a cause and effect relationship.

For apparently healthy adult striped bass, studies initiated by NMFS and followed up on by DFG found body burdens of various hydrocarbons and heavy metals, including mercury concentrations frequently exceeding U.S. Food and Drug Administration action levels. Eleven years of sampling found some evidence of poor health, such as egg resorption. However, no strong direct links were found between specific pollutants and fish health. Some indications of improving health were found during the eleven years.

Another avenue of exploration concerns a fish die off which has occurred each spring or early summer near the upper end of the salinity gradient for more than 40 years. Most deaths are of adult striped bass, with several thousand carcasses counted in some years. Several attempts to determine the cause of the die off have been unsuccessful, although recent University of California led studies have found evidence of liver damage and higher concentration of various hydrocarbons in moribund than control fish.

To reiterate, clear evidence of some harm from toxicants exists and warrants more effective management but overall consequences cannot be estimated. Given the major pollutant abatement actions during the last 20 years and some evidence of lessening effects of pollution, I find it difficult to believe that pollutants are a principal cause of the widespread decline in fishery resources which has occurred in the last 20 or so years.

Legal Harvest

Striped Bass -

DFG has measured the proportion of the bass population harvested by anglers periodically between 1958 and 1968 and annually since 1969. Since 1969 anglers have harvested an average of 19% of legal-sized bass annually with a range of 10 to 30%. No trend is evident over this period.

While these harvest rates are believed to be well within safe limits, angling regulations were made more restrictive in 1983 in an effort to increase protection for a declining population. Prior to 1983, the minimum length limit was 16 inches. In 1983, the minimum length was increased to 18 inches and the daily bag limit reduced from 3 to 2 fish. The respective legal length limits are equivalent approximately to bass being 3 and 3-1\2 years old.

In contrast, the combined angling and commercial harvest rates for striped bass in Chesapeake Bay were on the order of 50% annually, with harvesting starting at age 2.

The subject of safe harvest limits is discussed in more detail in the next section on illegal harvest.

White Sturgeon -

The risk of overfishing sturgeon is much greater than for striped bass, primarily because sturgeon do not mature until they are approximately twice as old as bass. In fact, no sturgeon fishing was permitted in California from 1917 until 1954 because sturgeon had become so scarce, probably due to overharvesting by a commercial fishery.

In 1954 a tightly regulated sportfishery was opened--1 fish per day bag limit, with minimum sizes ranging between 40 and 50 inches at various times since 1954.

DFG has measured harvest rates periodically since 1954. Annual harvest rates were less than 8% until 1984, when they increased to 9 to 11%. Concern that those higher rates were approaching dangerous levels resulted in adoption of more restrictive size limits (both increased minimum size and a maximum size). Subsequently, harvests have fallen to less than

5%. DFG is confident that sturgeon regulations are preventing overharvesting.

Salmon -

Management of the salmon fishery is complicated by there being both a sport and commercial fishery in the ocean and by the presence of several regulatory bodies. A sportfishery in freshwater is small in relation to the ocean fishery but has been increasing. Regulation was simplified and strengthened in 1976 by passage of the U.S. Fishery Conservation and Management Act which provides for regulation of ocean fishing on the Pacific Coast through the Pacific Fishery Management Council under the leadership of the Secretary of Commerce.

In recent years the Council has drastically curtailed the ocean fishery for salmon in an attempt to meet spawning stock escapement goals. Recently, the target escapement for the Sacramento system has been 122,000 to 180,000 Chinook salmon, a goal which has not been achieved in the last three years. No target is set for the San Joaquin system due to local habitat degradation and an inability to selectively manage the ocean fishery to promote San Joaquin escapement.

Harvest rates have not been measured for the entire salmon population as they have for striped bass and sturgeon. Instead the total catch of salmon south of Point Arena has been related to escapement in the Sacramento system to get an index of harvest rates. These rates have increased by an average of about 5% since 1970 but fluctuations throughout the period have been far greater than this average increase, with the highest rate being about 60% greater than the lowest. A limitation of the harvest rate index is that a substantial portion of the salmon from the Sacramento system rear north of Point Arena. Those salmon have received additional protection from stringent regulations north of Point Arena to protect Klamath River stocks.

Another issue concerning harvest regulations is the possibility that the increase in fishing effort supported by hatchery production has resulted in overharvesting wild stocks.

Ocean harvests clearly reduce spawning escapement substantially, but the most reasonable conclusion is that the fishery is not the principal factor limiting production. The best empirical evidence for that conclusion is the abundance of San Joaquin stocks. San Joaquin stocks provide good production in wet springs and poor production in dry springs. Total stocks fell to less than 1,000 spawners in both the 1959-61 and 1976-77 droughts. Within 2 generations spawning escapement rebounded to about 40,000 and 70,000 fish, respectively. That would not have been possible if overharvesting rather than spring flows had been the principal limiting factor.

Other Fishes -

Largemouth bass harvest rates by anglers were measured from 1980 through 1984. Rates were consistently about 30%, which is substantially less than largemouth harvest rates in many California reservoirs.

White catfish harvest rates by anglers were measured in the mid-1950s and again from 1978-1980. Catfish do not migrate very much, so harvest rates vary at different locations in the Estuary, presumably due to local differences in the amount of angling. In the latter study, harvest rates in different areas of the Delta ranged from 10 to 38%. Estimates of harvest in the 1950s were in the same range.

Summary -

A summary of legal harvest of various fishes is that in all cases harvest undoubtedly decreases the number of spawning adults and the average age of adults. Within limits, that is an inevitable consequence of harvesting any wild or domestic animal population.

The real questions are whether harvests are sufficient to inhibit the population's ability to maintain itself or to be responsible for observed changes in abundance. In every case where harvest rates have been measured for fish populations inhabiting the Bay-Delta system, no evidence was found indicating that the rates were either excessive or primarily responsible for recent declines in fish stocks. Any contention to the contrary must be viewed in of light concurrent declines in fish species which are not subject to either commercially or recreational harvest.

Illegal Harvest

Illegal harvest is more difficult to estimate than legal harvest, due to its clandestine nature. Some illegal harvest undoubtedly occurs for every species subject to fishing. A major goal of DFG is to minimize illegal take sufficiently to prevent harm to the resource and assure a socially acceptable division among resource users. DFG does not condone any illegal harvest and within the limits of its resources responds whenever evidence of illegal take is uncovered.

Within the Bay-Delta, the principal questions about illegal harvest concern salmon and striped bass. DFG believes that illegal take of salmon does not have a significant effect on the resource as a whole; this includes harvests by foreign fisheries.

Illegal take consequences are less certain for striped bass. They involve the illegal harvest of both legal and sublegal-sized bass. The magnitude of both is uncertain but the potential consequences of the take of legal-size bass can be evaluated with more certainty based on results of the tagging program.

Illegal take of legal-sized bass includes both taking more than the two fish bag limit using legal angling techniques and harvesting with gill nets. Many bass taken both ways are sold illegally for food.

In analyzing tag returns, tags returned to DFG are assumed to have been caught legally by anglers. While that is undoubtedly largely true, some illegally taken tags are probably returned as some tags have rewards as high as $20 for their return. To the extent tags from illegal fish are returned, illegal take would be included in the estimated harvest rates described in the section on legal harvest.

In addition to estimating harvest rates, biologists analyze tag returns to estimate total mortality. The difference between total mortality and harvest rates is generally called natural mortality. In reality, estimates of total mortality is a combination of natural mortality, illegal harvest and perhaps some legal harvest. The latter would occur if techniques used to estimate how many anglers fail to return tags from fish they catch underestimate that number.

The bottom line for the purpose of assessing illegal take is that estimates of total mortality include illegal take. Even though we can not estimate the percent of mortality caused by illegal take. Thus some insight into the combined effect of legal and illegal take can be derived from trends in total mortality.

From 1969 to 1973 and in several earlier years, total mortality averaged about 41%. After that it gradually increased to a plateau through the 1980s averaging 49%. DFG biologists estimate that this increase in total mortality of adults could account for about 25% of the decline in adult abundance observed since 1970.

That 25% is the maximum incremental impact of illegal fishing, assuming all of the increase in total mortality were due to illegal fishing. We do not know whether any of the increase is due to illegal fishing, and it seems most unlikely that all of it would be. For example, sea lions eat adult striped bass. Since they have increased their numbers and range with the Estuary, sea lion predation likely has contributed to the increased mortality.

Another perspective on total mortality is provided by experience on the East Coast. Some bass stocks there, including the largest stock which inhabits Chesapeake Bay, were being harvested by sport and commercial fisheries at a rate which resulted in total mortalities on the order of 70% per year. In the Chesapeake those fisheries started at age 2, rather than California's practice of limiting legal harvest to age 3-1/2 and older. Most Chesapeake biologists concluded overharvesting was the principal cause of bass declines observed on the east coast during the 1980s. They also concluded that total mortality on the order of 50% is sustainable.

The second portion of illegal take is the catch of sublegal bass. Historically, that has resulted entirely from anglers keeping some sublegal bass, but in recent years there has been some fishing with small nets.

Only the crudest of estimates exists. DFG wardens estimate they contact about 2% of anglers. Given that and the number of sublegal bass observed, they estimate that the take of sublegal bass is at least 500,000 fish per year.

The issue is not new. In the summer of 1957 or 1958, I spent a day patrolling with a warden, so he could document his concern over the take of sublegal bass. We saw a considerable number of sublegal bass being kept. Hence the issue concerns both the present magnitude and how that has changed.

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Contrasting the estimated illegal catch with the estimated ±400,000 3-year old bass in the population now, it is very likely that the illegal take significantly reduces the production of adult bass. The illegal catch estimates are very uncertain, and we have been unable to identify a way to improve them, so we can not estimate the consequences of illegal catch more precisely. While actions to reduce take are clearly warranted, the fact that illegal harvest of bass is not a new problem, and that it is well documented that increased mortality of younger bass is caused by the water projects, it seems unlikely that the harvest of sublegal bass is the dominant factor causing the decline in adult bass abundance since 1970.

Land Reclamation

Land reclamation caused major ecological changes both in the Estuary and throughout the Central Valley. It destroyed most of the tidal marshes in the estuary and seasonally flooded wetland upstream from the estuary. The latter probably caused the extinction of the thick-tailed chub, a minnow which spawned in seasonally flooded vegetation.

The vast majority of land reclamation occurred before 1920, so there is essentially no factual information available to estimate its consequences. The main issue for the purpose of this paper is whether modest rehabilitation of tidal or seasonal wetlands might have substantial value for rehabilitating fisheries.

The most significant may be for splittail. This native minnow has decreased in abundance to the point where it has been proposed for listing under the Federal Endangered Species Act.

Splittail often spawn over beds of submerged vegetation and the production of young is consistently much better in wet than dry years. Those two facts may be related. i.e. The amount of seasonally flooded vegetation may be great enough in wet years to cause the better production. Increasing the availability of wetlands at low flows might be an effective management strategy for splittail, but it would be strictly experimental and require substantial tracts of wetlands to increase production significantly.

Increased wetlands would undoubtedly cause other ecological changes, including increasing the production of organic detritus, but the actual nature of the changes are uncertain and large scale restoration would be necessary to have much effect on basic processes, such as increasing the base of the food chain through production of detritus. (Keep in mind that restoration cannot be accomplished by breaching the levees. In the Delta and even in Suisun Marsh, subsidence has been so great that breaching levees creates bays rather than marshes. Using dredge spoil to recreate wetlands offers some potential. It likely is responsible for the wetland created when the tip of Mandeville Island was severed during construction of the Stockton Deep Water Channel.)

In-Delta Diversions

Diversions onto Delta agricultural lands are made through many small unscreened intakes. During the peak of the irrigation season, the net amount of water diverted approximately equals the amount diverted through the Tracy Pumping Plant of the CVP.

Limited evaluations prior to 1970 documented losses of both salmon and striped bass by these diversions but were insufficient to estimate the overall magnitude of such losses. Losses undoubtedly vary due to the uneven geographic and seasonal distribution of fish, differences in intake design and location and other factors.

A more extensive evaluation of losses and potential screening methods is underway.

The largest other loss at diversions occurs at Pacific Gas and Electric Company's Contra Costa and Pittsburg Powerplants. The principal loss there is eggs and larvae of striped bass entrained in the cooling water for the plants structural and operational changes made in recent years pursuant to permits issued be the Regional Water Quality Control Boards have reduced such loss 50 to 70% in relation to losses occurring in the late 1970's.

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SUMMARY

A host of factors must be considered in formulating a fishery restoration plan for the Sacramento-San Joaquin Estuary. Enough is known to make sound judgments about the potential value of various actions, but not enough is known to design definitive restoration plans for the best known species, much less for the whole ecosystem.

Dealing with the effects of water development should be the cornerstone of any restoration plan. This involves providing adequate flows or salinities for various fishery needs, providing better fish screens and making some structural changes in the water distribution system to deal with adverse effects associated with the nature and location of the major water diversions.

Of the nonwater project related factors, control of toxicants and illegal harvest probably offer the greatest potential for assisting restoration. Prevention of further introductions of fish and invertebrates is important to avoiding additional, potentially harmful changes.